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To: Dr. D. Mills
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LABORATORY EVALUATION OF A RESIDENTIALLY-SIZED GROUND-SOURCE HEAT PUMP

F.J. Lenarduzzi and S. Yap

A residentially-sized heat pump capable of delivering up to 13 kW of heat was evaluated in the laboratory under steady-state conditions. The results show the heat pump can save 60% of the energy normally used to provide residential space and water heating when coupled to a ground coil appropriately sized to maintain an operating source temperature between 0°C and 5°C.

INTRODUCTION

Ground-source heat pumps offer a means of raising the natural energy stored in the ground to a useful temperature for space heating, water heating or other heating purposes. Unlike air-to-air heat pumps which undergo dramatic changes in efficiency and output as the outdoor temperature changes, ground-source heat pumps have the relatively constant temperature of the ground to provide a near constant output and efficiency all year long. To provide this constant output, heat is drawn from either well-water or from the ground itself.

Two heat pump units were evaluated in Ontario Hydro's heat pump research laboratory. This report summarizes the laboratory evaluation carried out from February 1984 to October 1985. Lower than expected performance characteristics with the first unit, not typical of the manufacturer's specifications, led to the manufacturer supplying a second unit for testing.

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The units tested (described in Appendix A) are single package, reversible, water-source heat pumps with an integral air handling system. They are capable of providing heating in winter, cooling in summer and hot water for domestic use. In this report, they were tested in closed-loop system mode at temperatures above and below freezing using glycol as a circulating fluid.

SYSTEM PERFORMANCE AND OPERATION

The performance of a heat pump is dependent on the source temperature (evaporating temperature) and the delivery hot air or water temperature (condensing temperature). Figure 1 shows the performance characteristics of the first heat pump tested over a range of glycol inlet temperatures. For all tests, the domestic hot water heating circuit was disabled thus the heat pump provided only space heating. Additional details on the testing conditions are given in Appendix A. A least-squares fit of the data indicates that at a source temperature of 0°C, the first heat pump coefficient of performance (COP) is 2.2 and the thermal output approximately 9 kW. These results were low compared to manufacturer's specifications and subsequent testing on a replacement unit yielded better results.

The performance characteristics of the replacement unit are shown in Figure 2. The lower COPs of the first unit seemed to indicate a problem with the glycol-to-freon heat exchanger used to extract heat from the ground loop. This was not the case in the second unit. For example, at a source temperature of 0°C, the COP of the replacement unit was found to be 2.7 and the corresponding thermal output approximately 13 kW. This represented a 23% increase in performance over the original unit and was in close agreement with manufacturer's specifications.

The heat pumps tested are capable of simultaneously providing both space heating and domestic hot water heating. In simultaneous heating mode, COPs for the units are similar to the results given above. This is because the heat needed for the water heater heat exchanger is supplied by the hot discharge gases from the compressor. Thus, the condensing pressure and consequently the overall output of the machine remains about the same as in the space-heating-only mode. The heat pumps can also operate in a hot-water-only heating mode. This would normally occur in spring or fall when neither space heating or cooling are needed. In the water-heater-only mode the COP is reduced to 1.8 at a water delivery temperature of 40°C to 50°C due to increased condensing temperature and pressure. In the summer, when both hot water heating and air conditioning are required simultaneously, the hot water heating is supplied virtually free since the heat pump's desuperheater captures waste heat from the house.

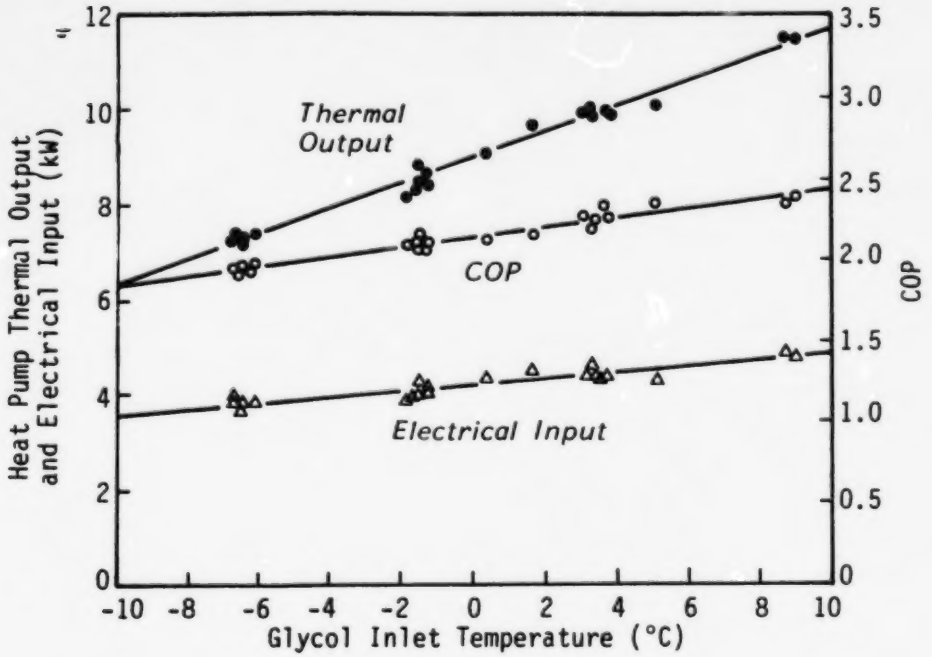

FIGURE 1

HEAT PUMP PERFORMANCE (INITIAL UNIT)

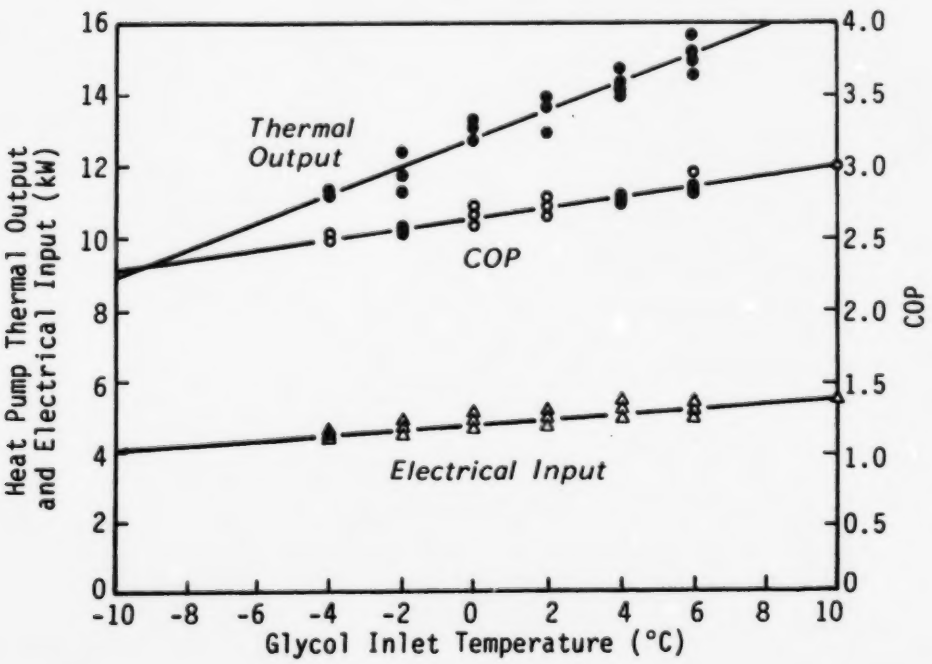

FIGURE 2

HEAT PUMP PERFORMANCE (REPLACEMENT UNIT)

CONCLUSIONS

1. Two samples of a commercially-available, residential ground-source heat pump were tested in both space-heating and hot-water heating modes. The first heat pump was replaced when performance measurements revealed a possible manufacturing defect.

2. The steady state heating mode COP of the first heat pump was 2.2 and its output was 9 kW at a glycol source temperature of 0°C. The second heat pump had a COP of 2.7 and an output of 13 kW at the same source conditions.

3. In actual residential applications, the second heat pump would save approximatley 60% of the heating costs compared to a similar house with electric resistance heating.

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APPENDIX A

HEATING SYSTEM DESCRIPTION

In the heating mode, the heat pump provides warm air and hot water by extracting heat from an antifreeze solution which would normally circulate to a ground-coil circuit of buried plastic pipes. For the laboratory evaluation an electric immersion heater simulated the ground coil (see Figure 3).

The antifreeze solution is either a brine mixture of 20% calcium chloride by weight and water, or a solution of ethylene glycol or propylene glycol antifreeze. For the first heat pump, an ethylene glycol and water mixture of 50% by volume was used and referred to as the glycol solution. Based on the manufacturer's recommendation, the replacement heat pump had an ethylene glycol solution of 25% by volume. Figure 3 schematically illustrates the heat pump test set-up showing the monitoring equipment, hot water tank and heat pump.

Figure 4 schematically shows the heat pump's refrigerant circuit in the heating mode. The entire refrigerant circuit is factory sealed which means these heat pumps could potentially be installed by personnel not qualified as refrigeration mechanics. Figure 4 also shows that the heat pump can provide air conditioning by way of a reversing valve.

The heat pump has a logic system that gives water heating priority even if space heating is needed. The potable water heating cycle is initiated when the average domestic hot water tank temperature falls below 45°C. If forced-air space heating is taking place when this occurs, the blower stops, though the condenser still receives hot freon gas.

The potable domestic hot water in the storage tank is heated by a water jacket around the tank. This water jacket is heated by a closed hot water loop that absorbs heat from a desuperheater (a freon-to-water heat exchanger in series with the condenser). The hot water in the closed loop circulates by a pump integral with the heat pump and can be expanded to provide pool heating or hydronic heating if required. This intermediate loop also serves to provide the "double-wall" isolation required by some plumbing codes between the freon and the potable hot water.

ENERGY MEASUREMENTS

To evaluate the performance of this heating system the following three energy quantities were monitored.

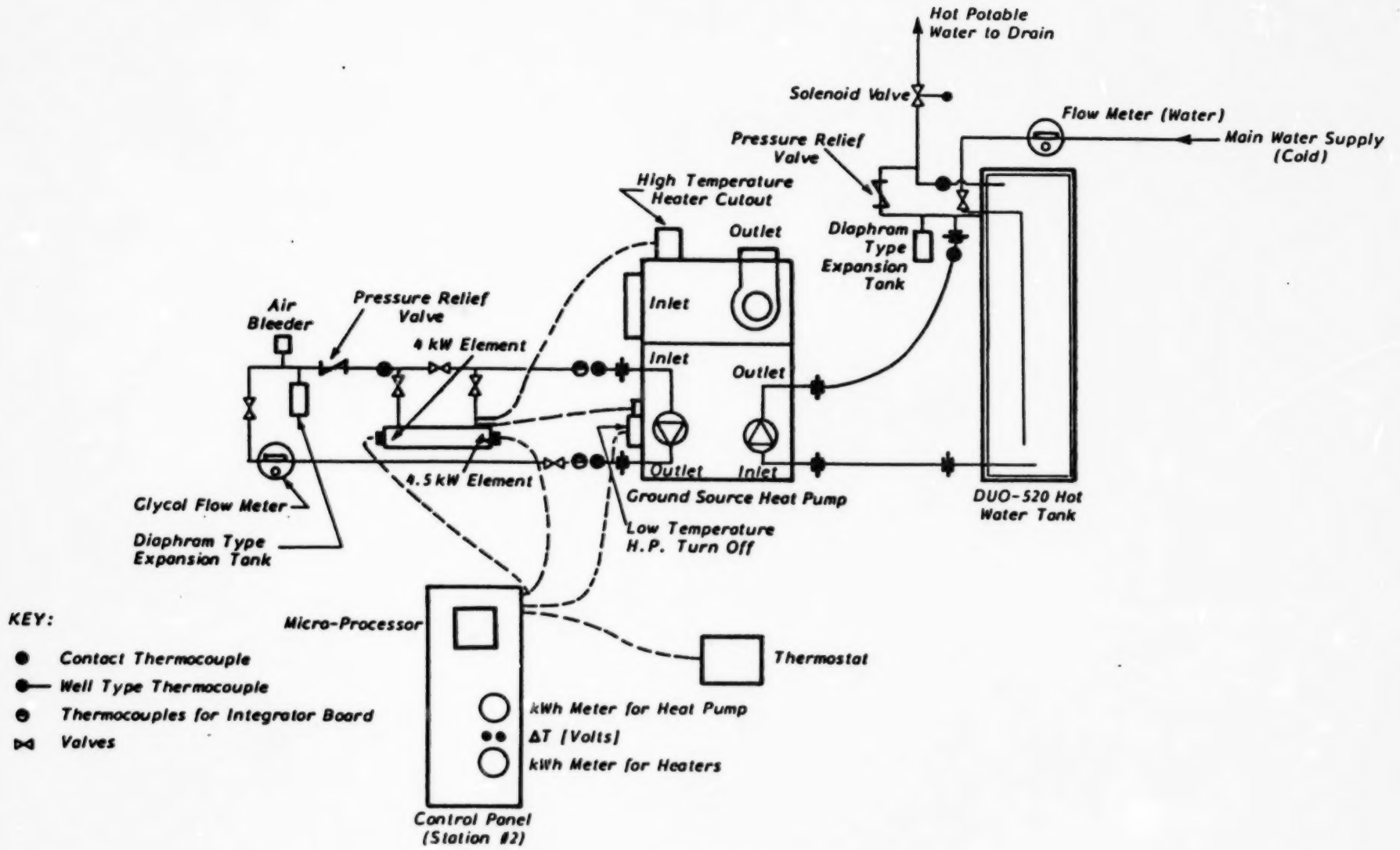

FIGURE 3

SCHEMATIC OF THE TEST SET-UP

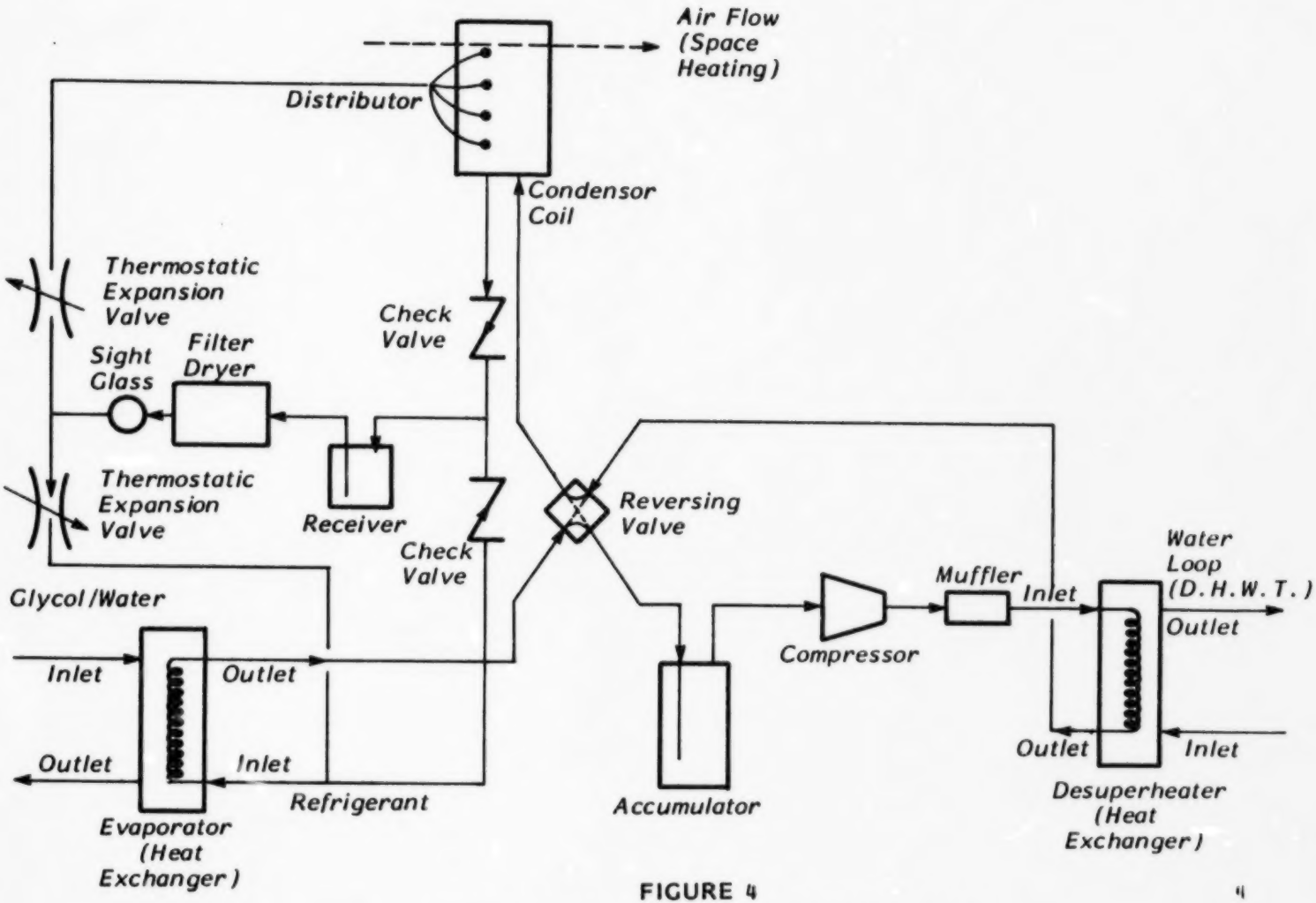

FIGURE 4

EXPERIMENTAL HEAT PUMP REFRIGERANT
CIRCUIT FOR SPACE HEATING

1. GE - Energy removed from the glycol solution by the heat pump.

2. HE - Electrical energy consumption of the immersion heaters used to control the temperature of the glycol solution.

3. HPE- Electrical energy consumption of the heat pump system, which includes compressor, blower, two pumps and controls.

In addition, temperature measurements were made at locations identified in Figure 3 and continuously recorded on an automatic chart recorder. On the indoor side return air to the heat pump was typically maintained at 22°C.

With these quantities known and input temperatures monitored and controlled, sufficient information was available to evaluate the heat pump performance. Expressed in its simplest form, for a heat pump:

$$\text{Coefficient of Performance (COP)} = \frac{\text{Total Useful Output}}{\text{Total Electrical Input}}$$

In the case of the ground source heat pump under test:

$$\text{COP} = \frac{\text{GE} + \text{HPE}}{\text{HPE}}$$

ERROR ANALYSIS

The accuracy of electrical energy quantities measured by the watt-hour meters is considered to be within 1%. The heat flow meter used to measure the energy extracted from the glycol solution is considered less accurate, even though careful laboratory calibration of the instrument was performed during the evaluation (see Appendix B).

A conservative estimate of the possible measurement errors indicates the measurements of the energy absorbed by the heat pump from the glycol loop to be within $\pm$5%. Since the energy flow in the glycol loop makes up only part of the energy used to calculate the COP of the system, the final COP values are accurate to $\pm$2.5% or $\pm$0.05 COP units.

APPENDIX B

CALIBRATION OF THE HEAT FLOW INTEGRATOR (HFI)

The heat flow integrator (HFI) measures and records the energy flow of a liquid circulating system. To calibrate the HFI four heater values as measured by a kilowatt-hour meter (0 kW, 4 kW, 4.5 kW and 8.5 kW) were used.

The test compared the output from the HFI to the kilowatt-hour meter reading. Ideally, the powers calculated by the HFI and the kilowatt-hour meter reading should be equal. But due to inherent and external inaccuracies, differences existed.

The two power quantities were calculated in the following manner:

a) Power delivered by the heaters and measured by the kilowatt-hour meter

$$P = \frac{DR}{t} \times K_h \times 3600$$

where P - power delivered to the heaters as measured by the meter (W)
DR - number of disc rotation (Rev)
K_h - meter constant (W·h/Rev)
t - time for disc rotations (s)
3600 - conversion factor (s/h)

The meter used in this experiment was itself calibrated by Ontario Hydro's instrument laboratory to be accurate within $\pm$0.5%.

b) Power calculated by HFI

$$P = \frac{Pulses}{t} \times HFIC \times 3600$$

where P - power calculated by the HFI (W)
Pulses - The number of contact closures from the heat flow integrator.
HFIC - Heat flow integrator constant 8.5774 W·h/Pulse
t - time for pulses (s)

Using the least squares regression technique, the calibration curve has been plotted in Figure 5. The heat flow integrator constant was calculated to be 8.5774 W·h/Pulse.

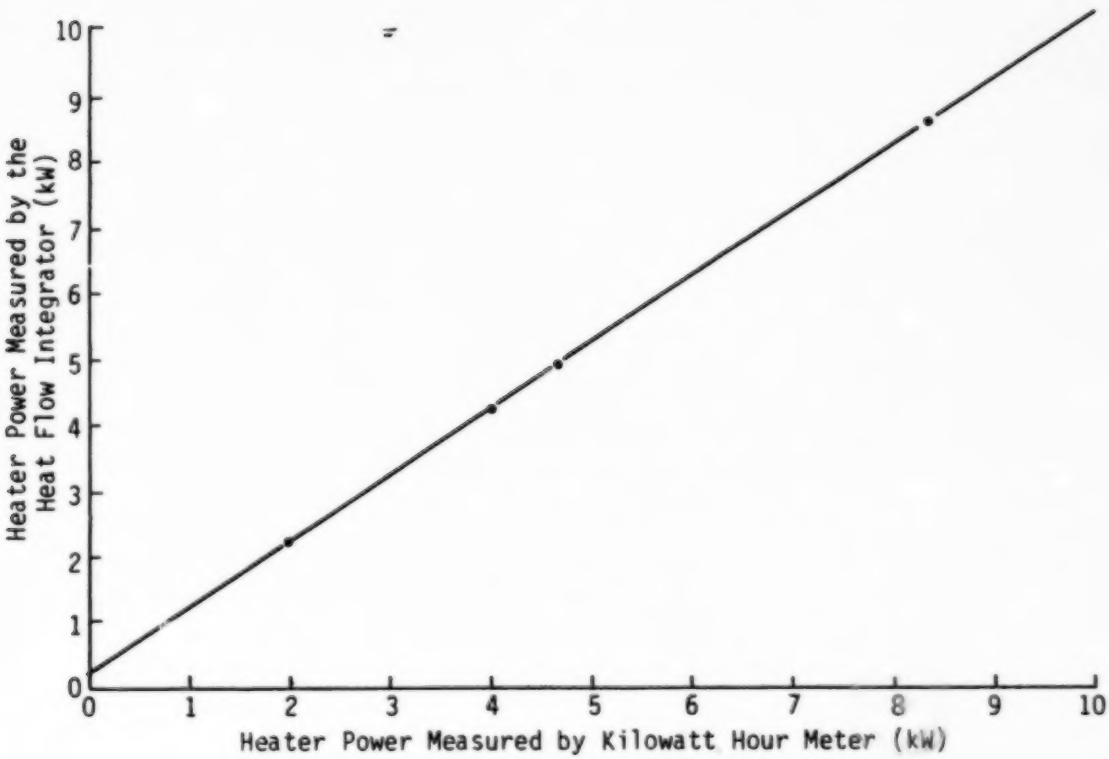

FIGURE 5
CALIBRATION CURVE FOR H.F.I.